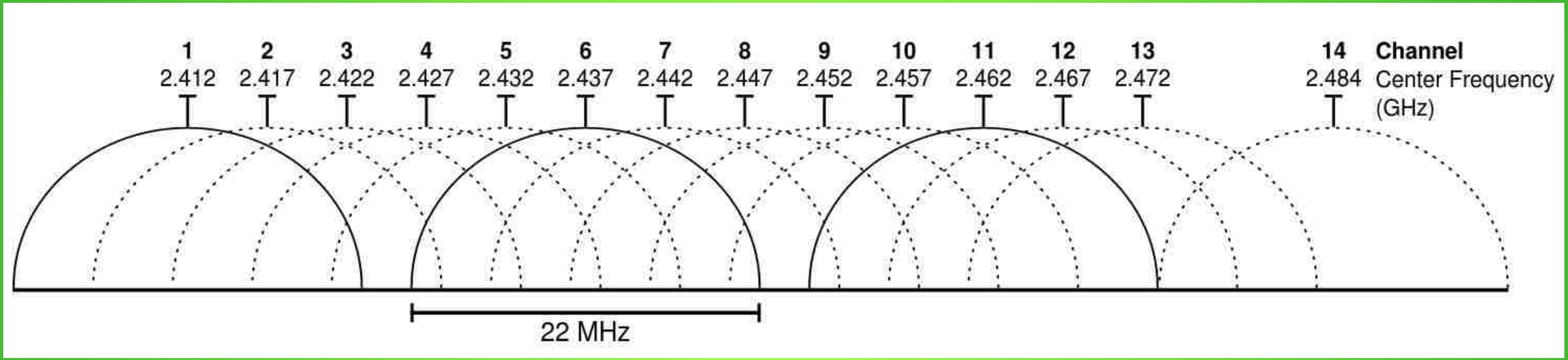
TV-Whitespace
More radio spectrum for the commons

freifunk.net

mabb_

(“Directors cut” of the slides used at re:publica, WCW2015, Battlemesh V8, CCC-Camp 2015, “Das war Netzpolitik 2015”, MABB with additional comments)

What happened so far...



ETSI WiFi channels 1 - 13 @ 2.4 GHz

A study by the EU Commission about mobile offloading of data traffic has calculated that the annual cost savings of the mobile network operators through the use of WiFi in 2015 sums up to 84 billion euros.

250 million units in Germany use WiFi - on three channels in a "garbage" or “trash” band.

Spectral Efficiency

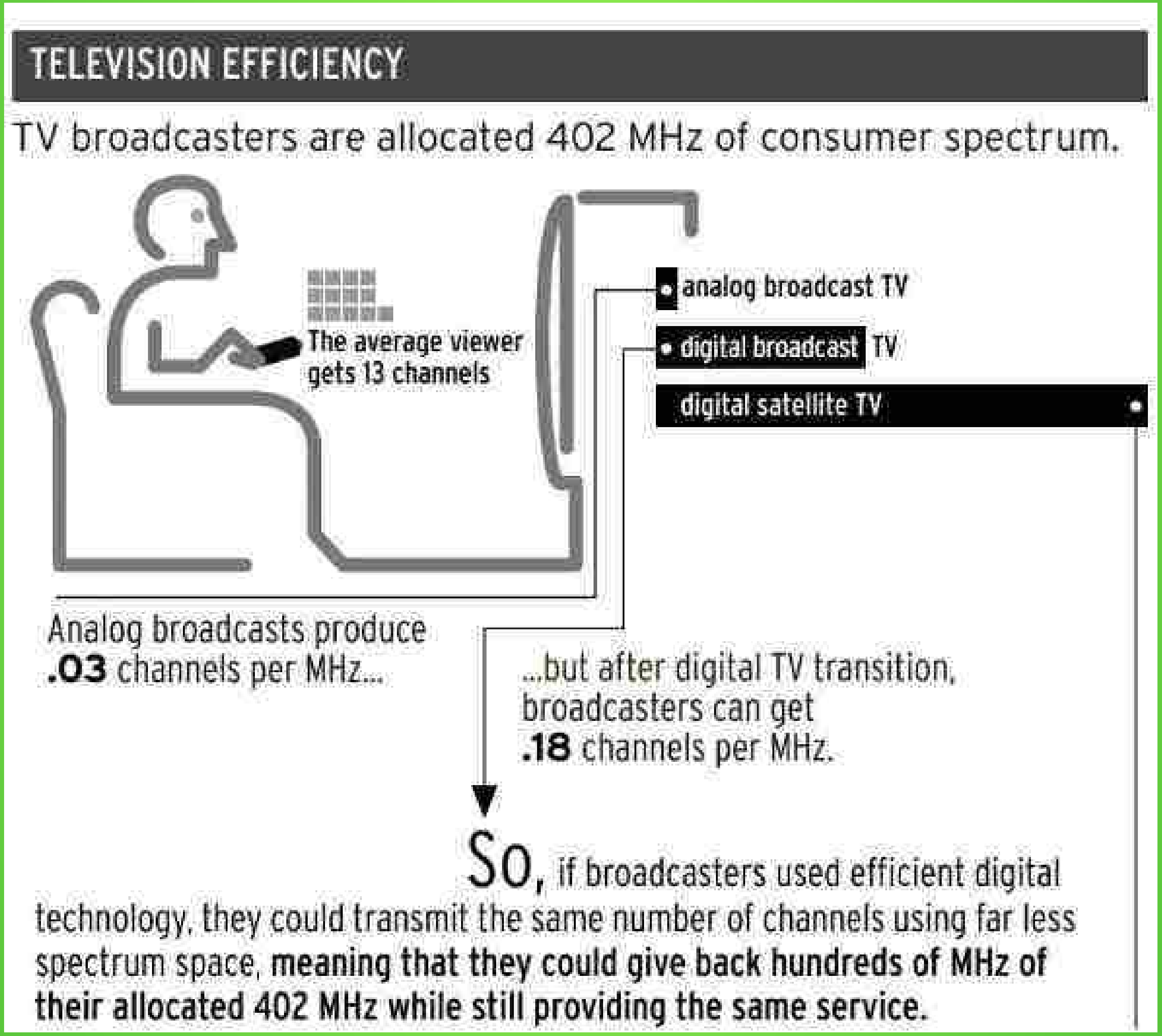


Image source: New America Foundation

Digital Dividend

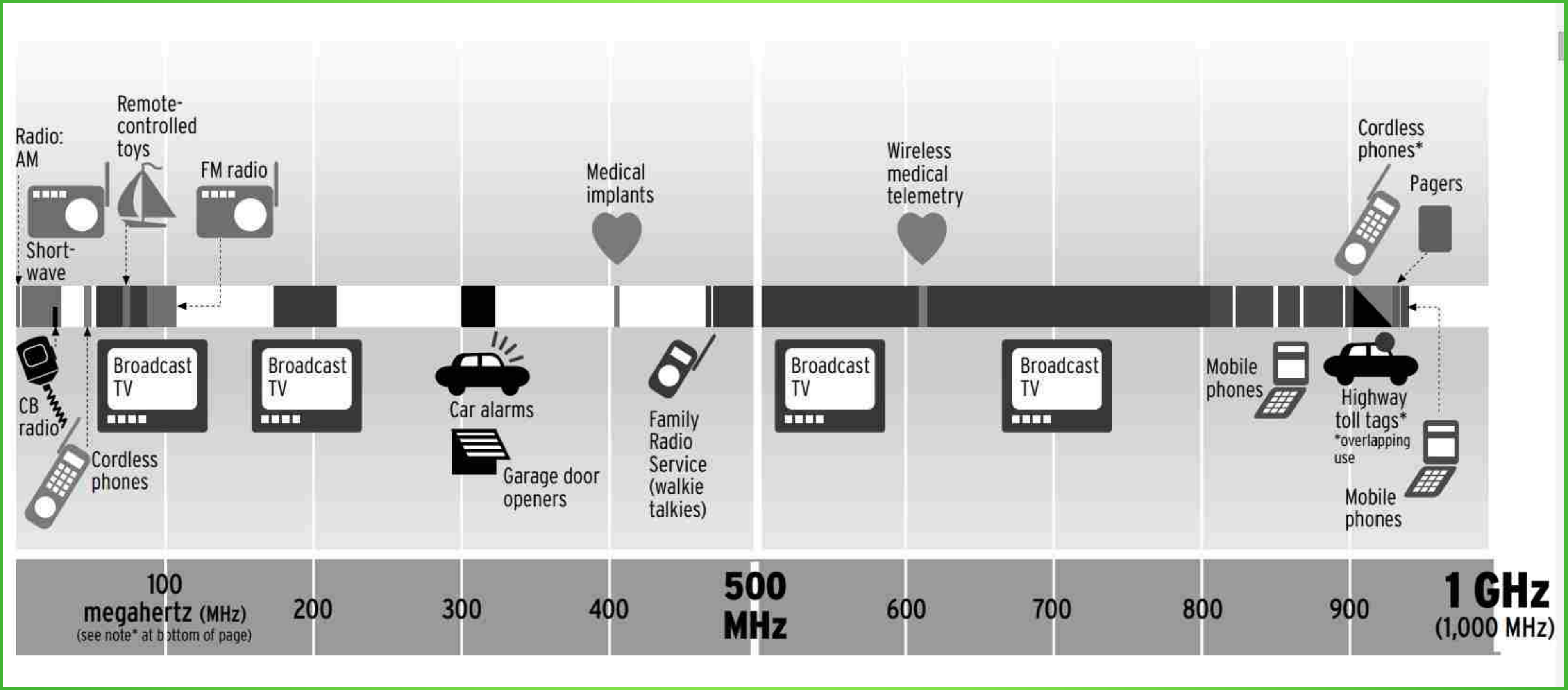
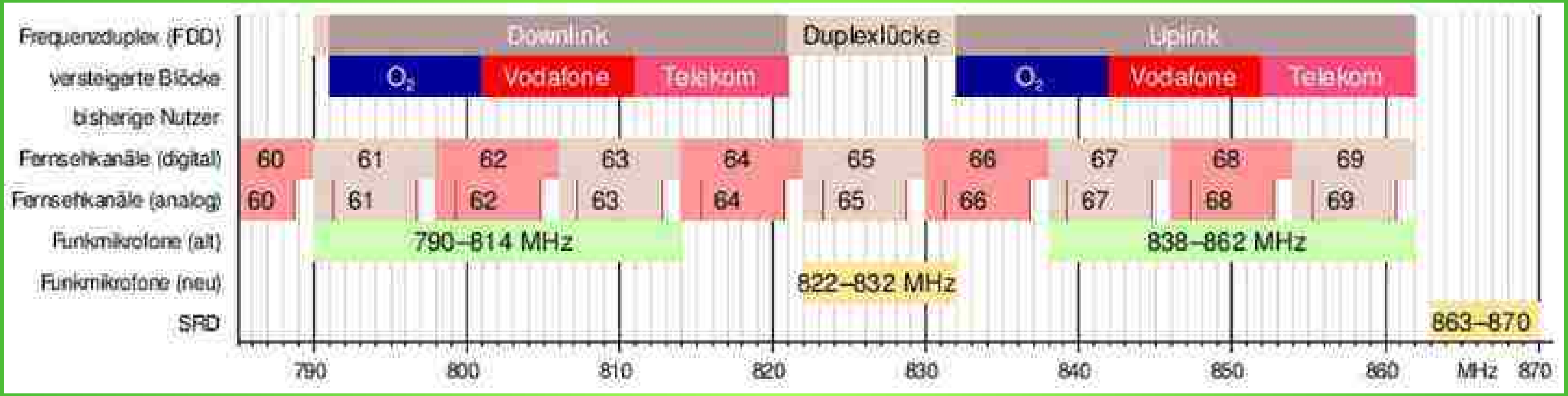
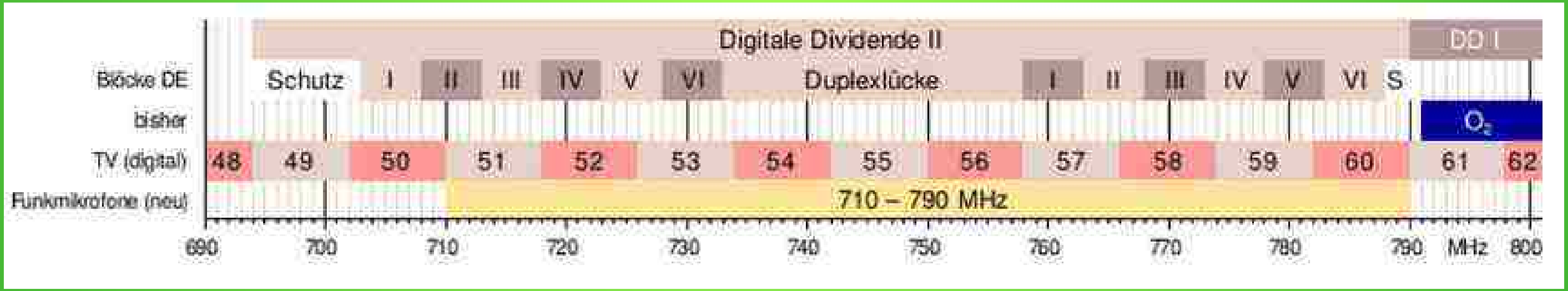


Image source: New America Foundation

The digital dividend in Germany





Auctioned on June 19th, 2015 to Telefónica, Telecom and Vodafone for 5.081.236.000 €.

German tax payers laughing all the way to the bank?

	Uplink	Downlink	Preis 2010
O_2	5 MHz im Bereich 832,0–837,0 MHz	5 MHz im Bereich 791,0–796,0 MHz	616,595 Mio. €
O_2	5 MHz im Bereich 837,0–862,0 MHz	5 MHz im Bereich 796,0–821,0 MHz	595,76 Mio. €
Telekom	5 MHz im Bereich 837,0–862,0 MHz	5 MHz im Bereich 796,0–821,0 MHz	570,849 Mio. €
Telekom	5 MHz im Bereich 837,0–862,0 MHz	5 MHz im Bereich 796,0–821,0 MHz	582,949 Mio. €
Vodafone	5 MHz im Bereich 837,0–862,0 MHz	5 MHz im Bereich 796,0–821,0 MHz	583,006 Mio. €
Vodafone	5 MHz im Bereich 837,0–862,0 MHz	5 MHz im Bereich 796,0–821,0 MHz	627,317 Mio. €

What wireless broadband users in Germany are going to pay for...

Unternehmen	Frequenzmenge		Zuschlagspreis
Telefónica Deutschland GmbH & Co. OHG	700 MHz: 900 MHz: 1800 MHz:	2 x 10 MHz 2 x 10 MHz 2 x 10 MHz	1.198.238.000 €
Telekom Deutschland GmbH	700 MHz: 900 MHz: 1800 MHz: 1500 MHz:	2 x 10 MHz 2 x 15 MHz 2 x 15 MHz 20 MHz	1.792.156.000 €
Vodafone GmbH	700 MHz: 900 MHz: 1800 MHz: 1500 MHz:	2 x 10 MHz 2 x 10 MHz 2 x 25 MHz 20 MHz	2.090.842.000 €
Gesamt	**270 MHz**		**5.081.236.000 €**

Why only commercial providers?

- Privatization of a public resource
- "The market will handle such things."
- "He" does not do it, as we see in many rural areas due to the of lack of supply. In sparsely populated areas the incentive is very low.

Proposal: A dedicated license-exempt WiFi band in the UHF range for everyone!

- 80-100 MHz wide.
- All players would win (consider mobile offloading)
- No problems with databases.
- No problems with "Hidden Nodes"
- The public resource television spectrum remains a public property.
- We could just change the frequency band of existing WiFi solutions and start to use it.

Why wavelength matters

Image: Shalom Jacobovitz CC-by SA 2.0

If the big wave hits the surfer, the wave won't break. On the other hand, a wave of the size of a surfer will break, if it hits an oil tanker. Likewise, isolated conductive objects, that are much smaller in length than the wave length of an electromagnetic wave front, will also have a very limited effect to the electromagnetic wave front.

Fresnel Zone

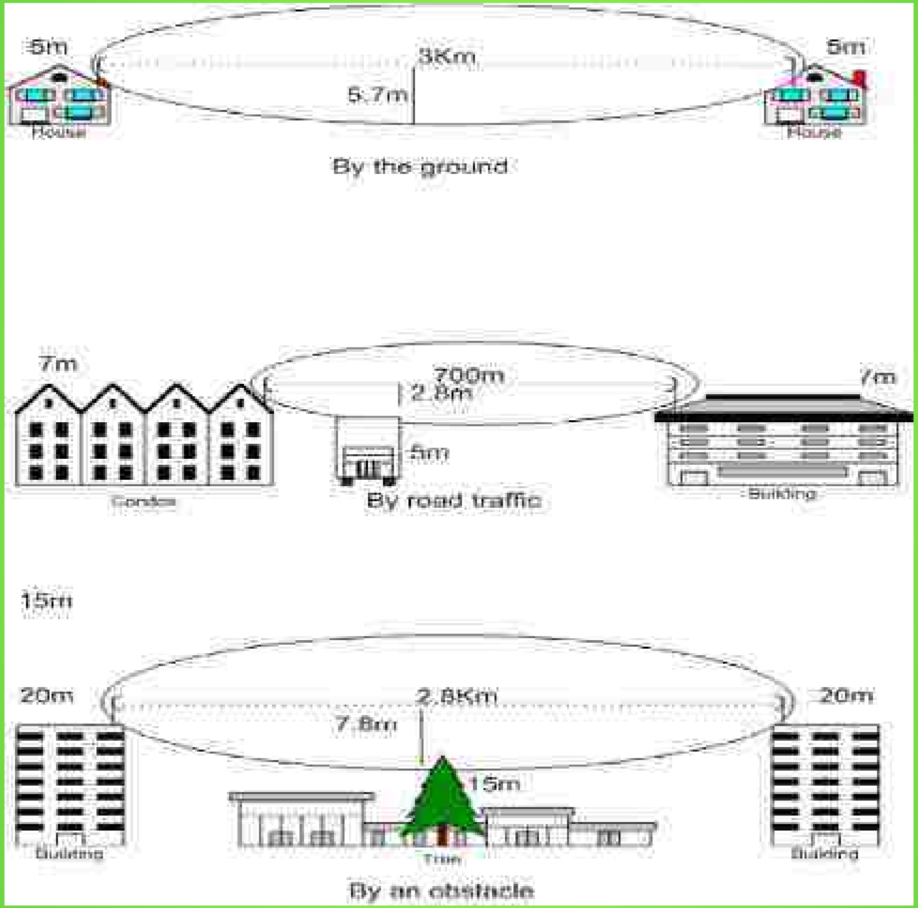


Image: Kgrr, CC-by-SA 2.5

Objects of considerable size in relation to the wavelength in the so-called Fresnel zone area between the antennae of a communication link, are affecting (breaking) the wave front. The results are attenuation and new wavefronts that are out of phase, which adds to the noise floor on the channel.

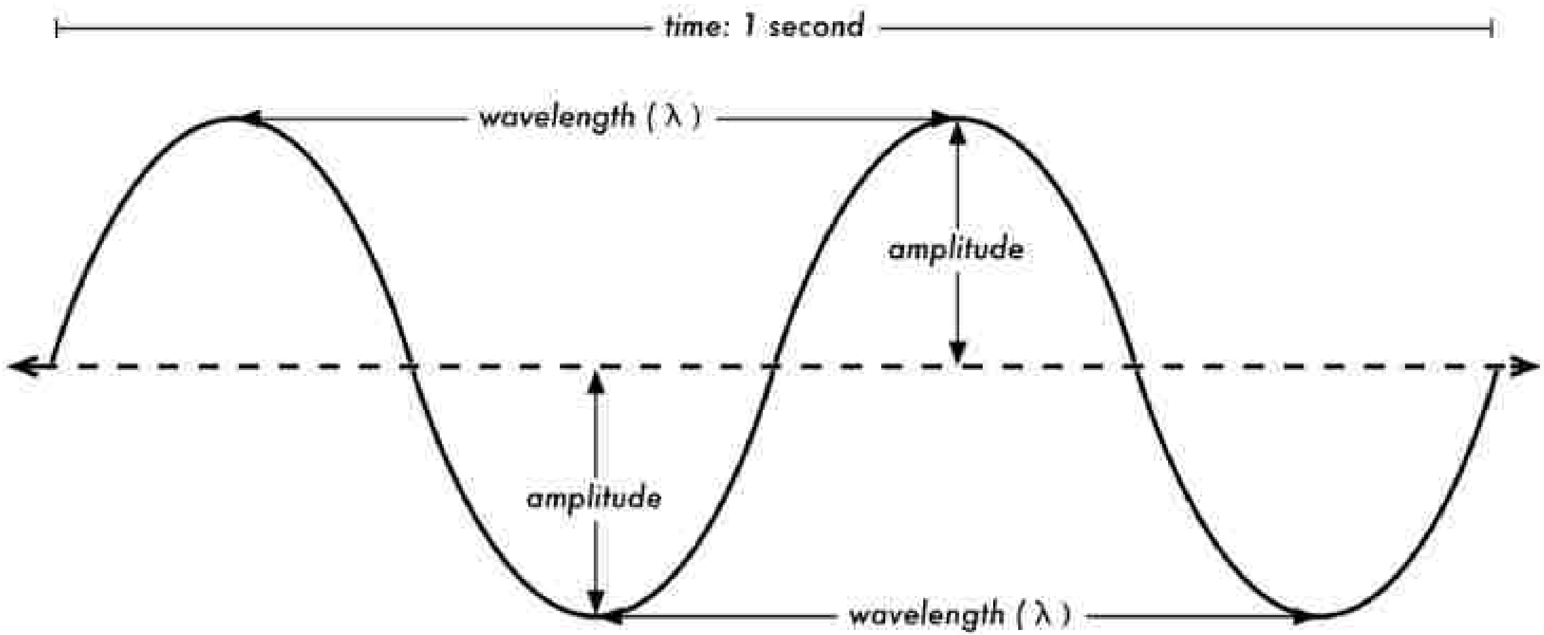


Figure RP 1: Wavelength, amplitude, and frequency. For this wave, the frequency is 2 cycles per second, or 2 Hz, while the speed is 1 m/s.

Wavelength explained:
Electromagnetic waves travel at the speed of light (~300.000 km/s)
If a wave has a frequency of 2 cycles per second (2 Hz), it will travel 150.000 km while going through one complete cycle. Hence, the wave length of an electromagnetic wave at 2 Hz is 150.000 km. 2.4 GHz WiFi operates at around 2.440.000.000 cycles per second. If you do the math, the wavelength is around 12 cm, and ~ 5 cm, if you use 5 GHz WiFi channels.

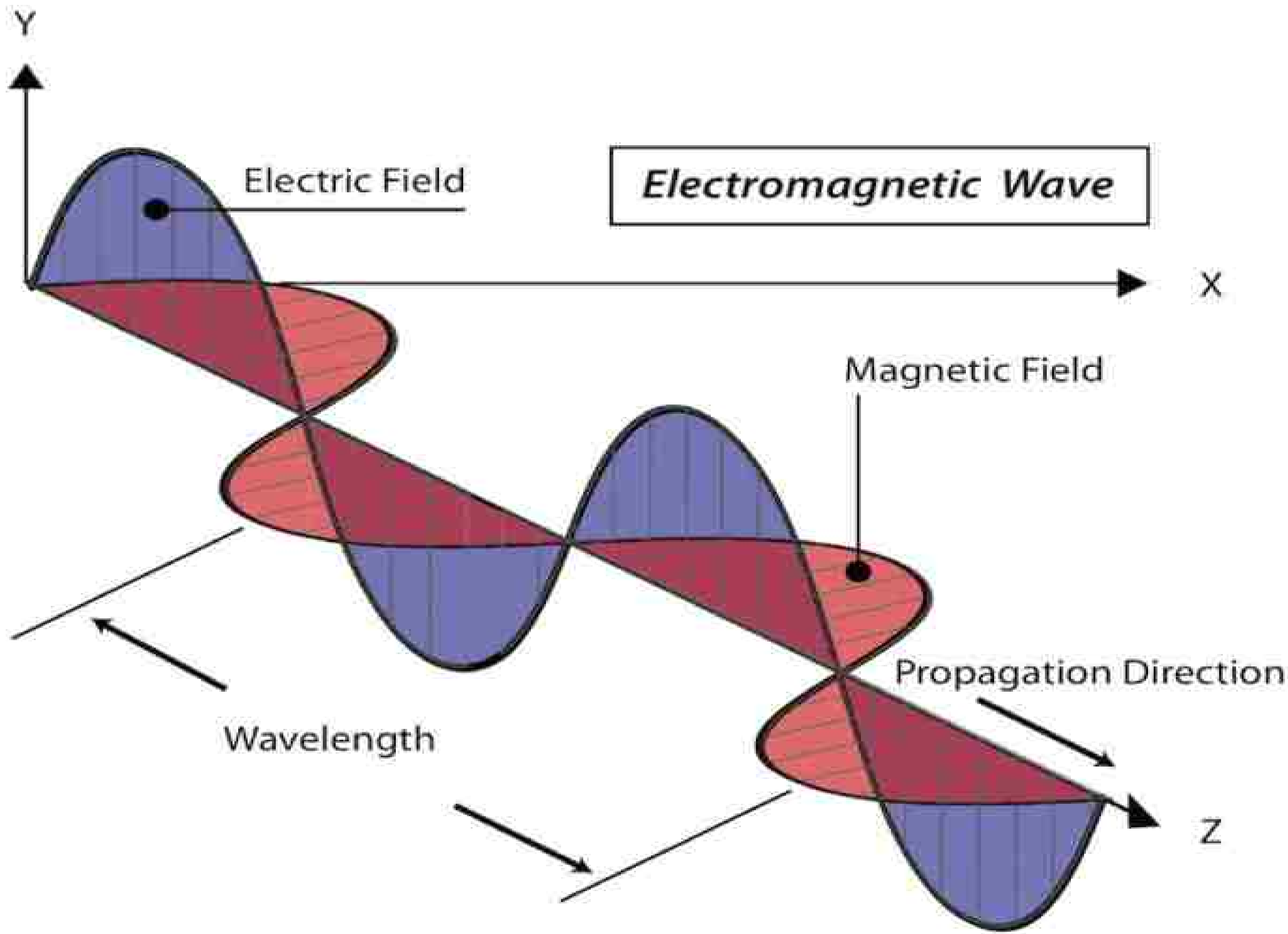
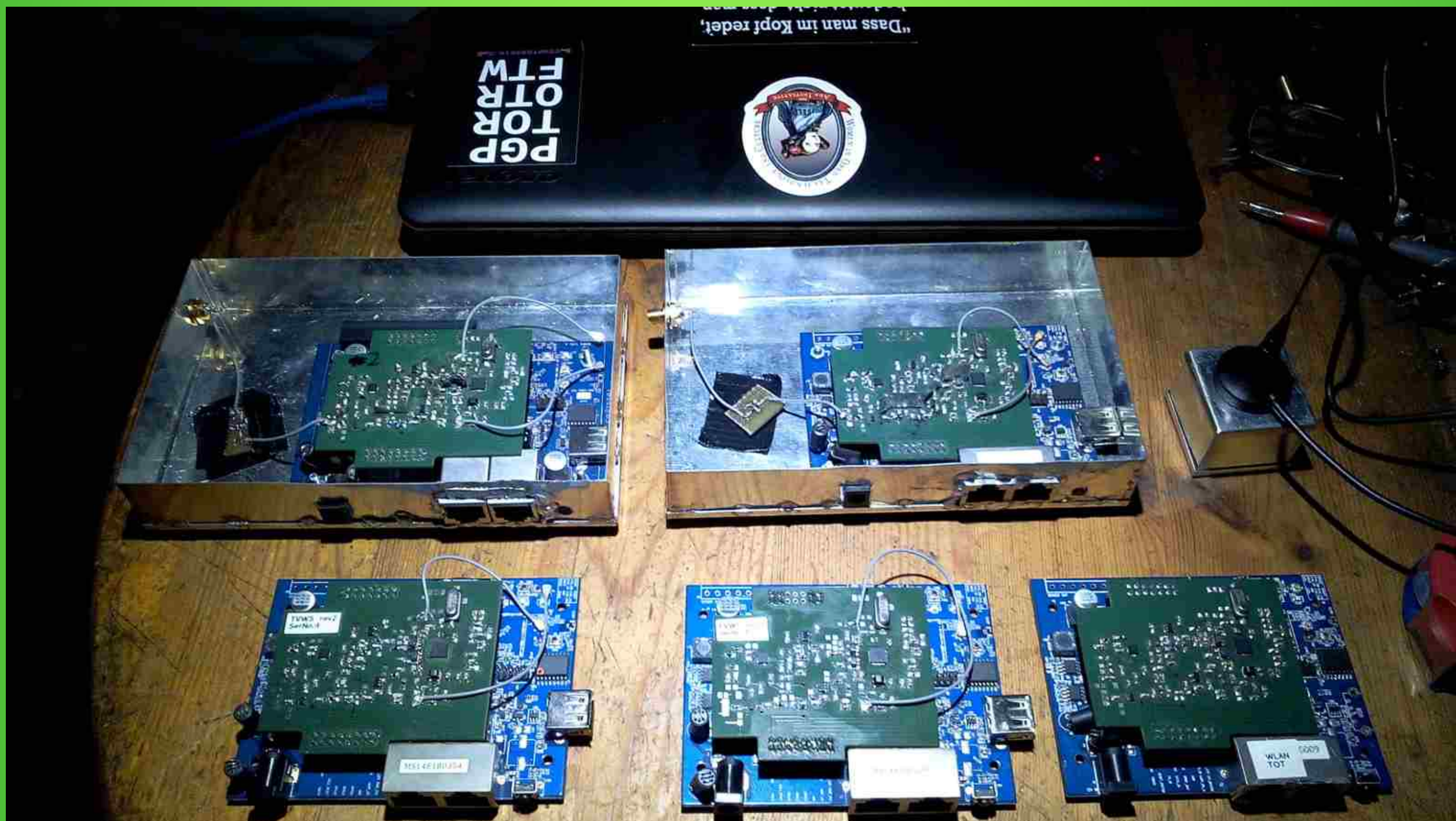


Figure RP 3: Vertically polarized electromagnetic wave

As the wavelength gets longer, antennas tend to get bigger...

8dBi collinear dipole for 62 cm wavelength (482 MHz – TV-Channel 22 UHF)

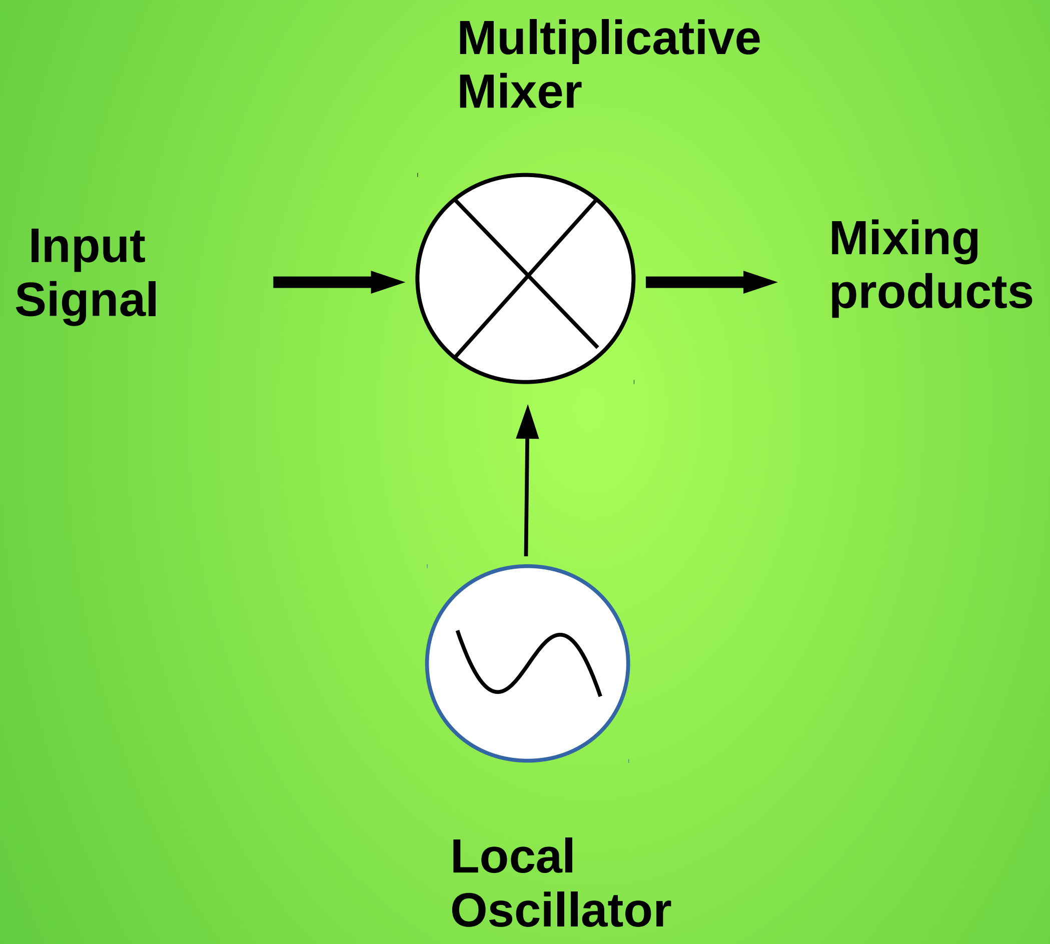
Freifunk-Prototypes for 482 MHz



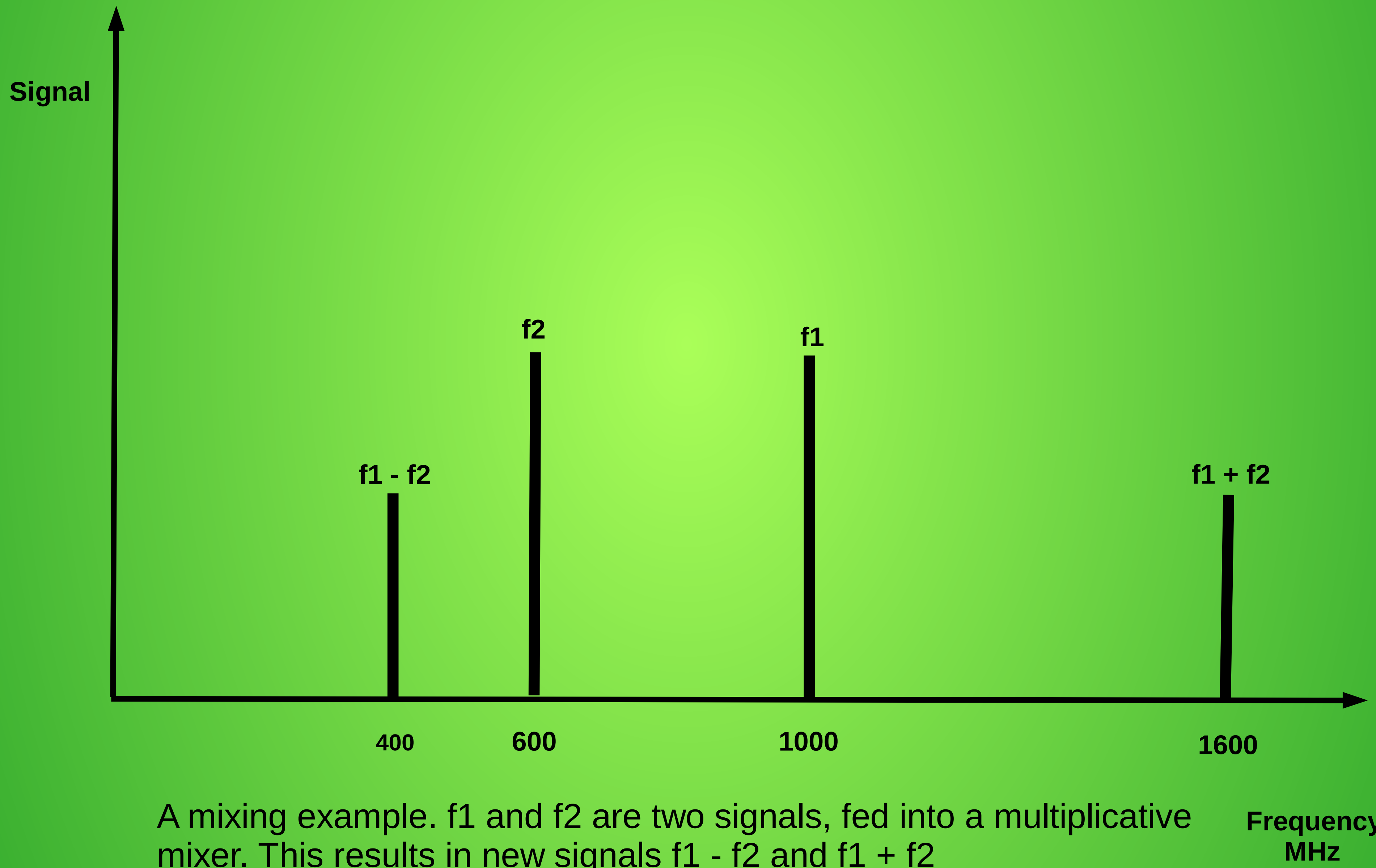
How?

Up/down convert a 802.11n 2.4 GHz signal to the desired frequency band by multiplicative mixing.

Multiplicative Frequency Mixing

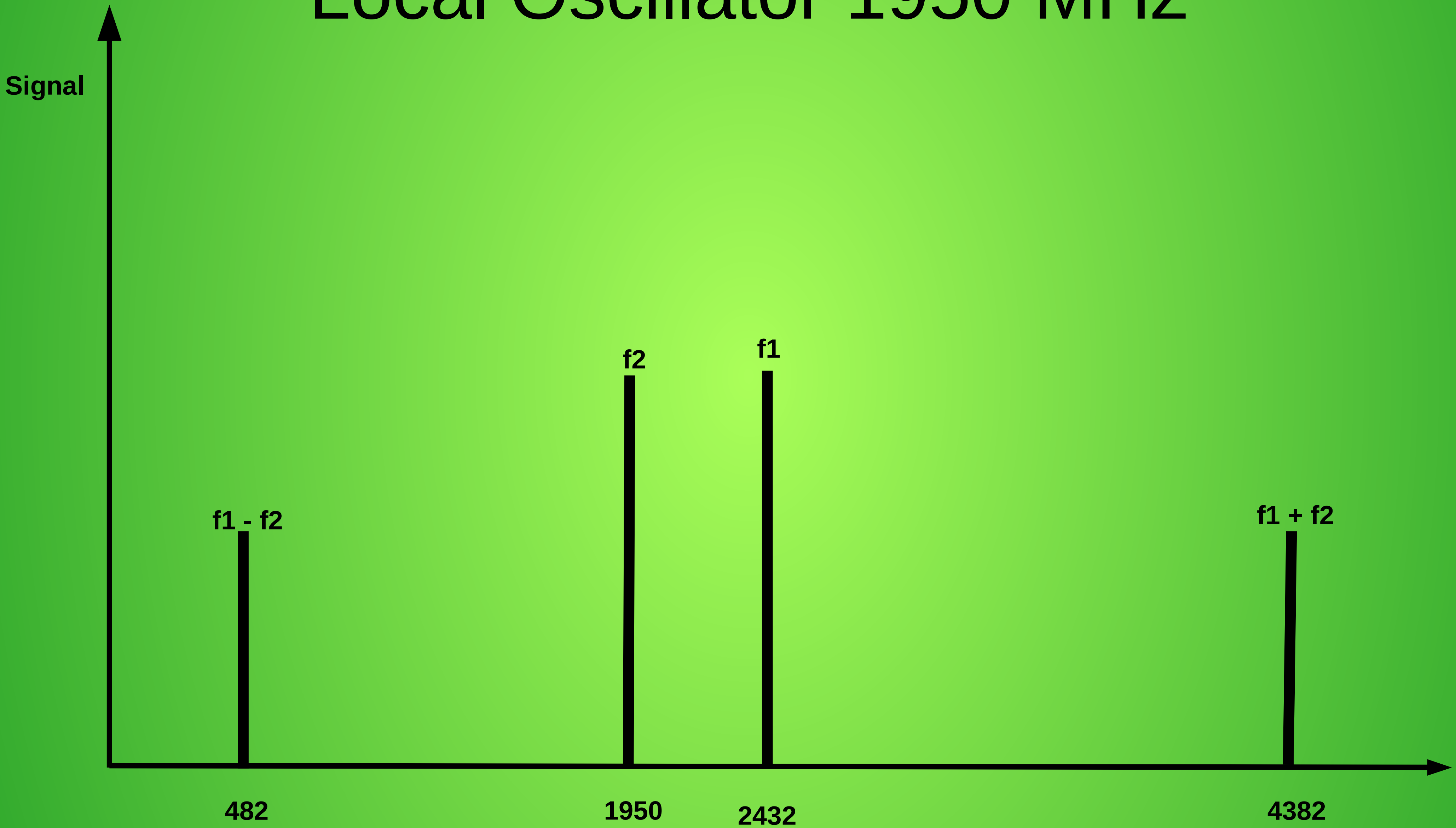


Multiplicative frequency mixing 2



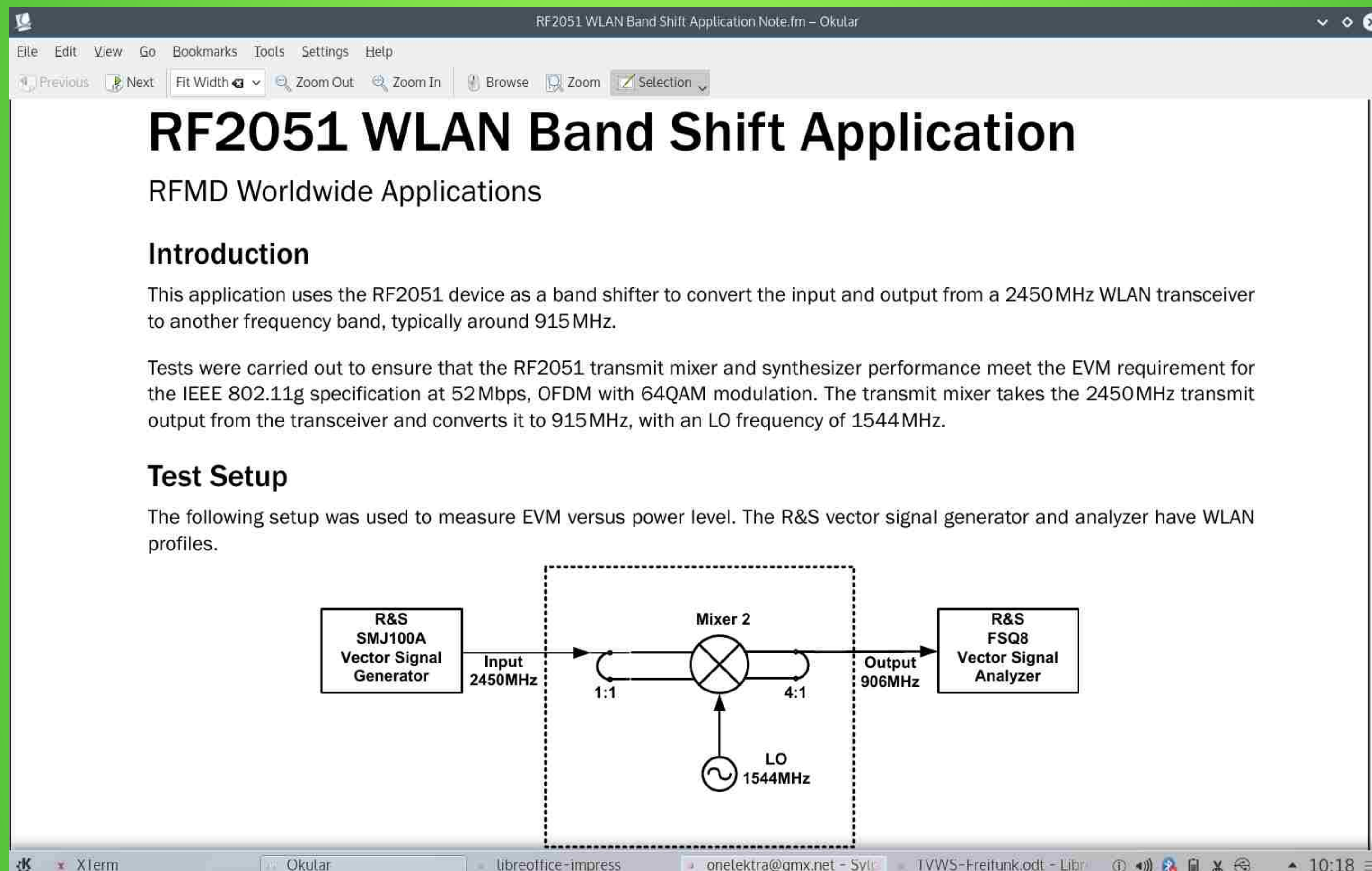
A mixing example. f1 and f2 are two signals, fed into a multiplicative mixer. This results in new signals f1 - f2 and f1 + f2

Wifi 2.432GHz (Channel 5), Local Oscillator 1950 MHz



Concrete example. We use the signal f1 – f2. f1 + f2 is unwanted. All values in MHz.

Band shifting app note RFMD IEEE802.11g



RF2051 WLAN Band Shift Application

RFMD Worldwide Applications

Introduction

This application uses the RF2051 device as a band shifter to convert the input and output from a 2450MHz WLAN transceiver to another frequency band, typically around 915MHz.

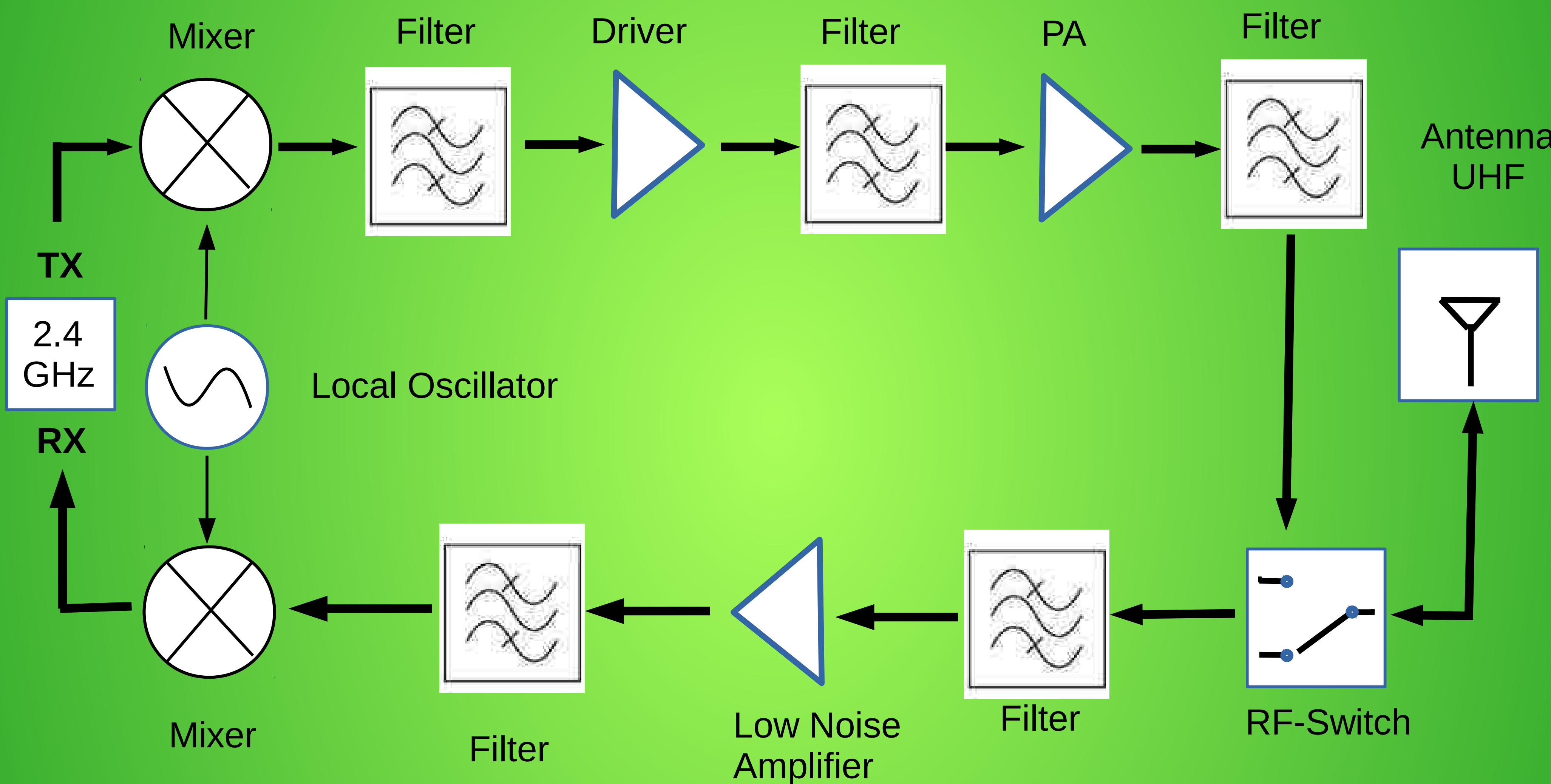
Tests were carried out to ensure that the RF2051 transmit mixer and synthesizer performance meet the EVM requirement for the IEEE 802.11g specification at 52Mbps, OFDM with 64QAM modulation. The transmit mixer takes the 2450MHz transmit output from the transceiver and converts it to 915MHz, with an LO frequency of 1544MHz.

Test Setup

The following setup was used to measure EVM versus power level. The R&S vector signal generator and analyzer have WLAN profiles.

While looking for a suitable integrated circuit for multiplicative mixing of WiFi signals, we came across this application note from RF-Micro-Devices.

2.4 GHz to UHF Transverter Block Diagram



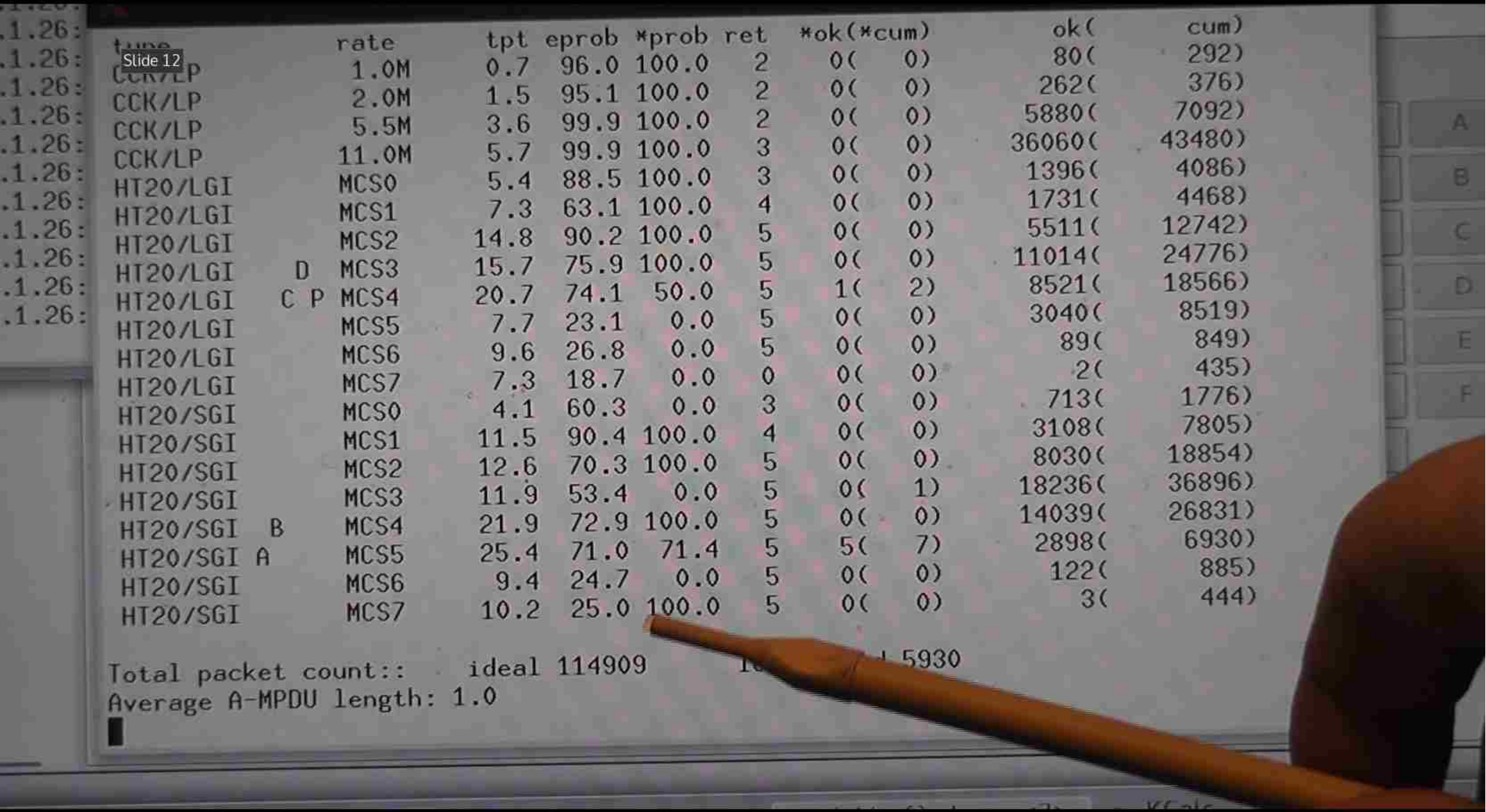
There is a long way from the simple application note test in the lab by RFMD and a complete transverter solution, though. The RFMD app note merely shows that the mixer is capable to convert a 802.11g WiFi signal one way. That's just two building blocks out of many.

Challenges on the way to a working design

- The mixer attenuates the converted output signal versus the input signal by approx. 4 dB (bad) while adding noise (bad). We suffer from these effects twice – when we mix the frequency down on the transmitting side and when we mix the frequency up on the receiving side. We have to compensate this with amplification. The added noise from the mixer is a trade off of this type of design that we have to accept. We have to keep it to a minimum.
- The mixer can compress the signal (bad). So drive it with low power input signal and high mixer current.
- The local oscillators phase noise will degrade the WiFi signal (bad). So the local oscillator must be of low phase noise design.
- We need filtering to remove unwanted mixing products, namely f1, f2, f1+f2 in the transmit path and particularly 2.4 GHz signals from nearby WiFi devices in the receiving path. Filters will attenuate the signal and thus can also cost performance. Filters can also be used for impedance matching (good).
- Since the down-converted TX signal we get from the mixer is weak and our filters attenuate the signal, we need hi-gain of amplification. Amplifiers need impedance matching and tend to ring (and thus add distortions and noise (bad), particularly when operated at high gain. Requires careful design.
- Frequency drift of the local oscillator will add to the frequency drift of the WiFi device that the transverter is connected to. WiFi devices always have to deal with frequency drift, however, if the drift is too large, the performance degrades.
- And much more...

Challenge accepted.

Band shifting IEEE802.11n result



Slide 12

type		rate	tpt	eprob	*prob	ret	*ok(*cum)	ok(cum)
CCK/LP		1.0M	0.7	96.0	100.0	2	0(0)	80(292)
CCK/LP		2.0M	1.5	95.1	100.0	2	0(0)	262(376)
CCK/LP		5.5M	3.6	99.9	100.0	2	0(0)	5880(7092)
CCK/LP		11.0M	5.7	99.9	100.0	3	0(0)	36060(43480)
HT20/LGI		MCS0	5.4	88.5	100.0	3	0(0)	1396(4086)
HT20/LGI		MCS1	7.3	63.1	100.0	4	0(0)	1731(4468)
HT20/LGI		MCS2	14.8	90.2	100.0	5	0(0)	5511(12742)
HT20/LGI	D	MCS3	15.7	75.9	100.0	5	0(0)	11014(24776)
HT20/LGI	C P	MCS4	20.7	74.1	50.0	5	1(2)	8521(18566)
HT20/LGI		MCS5	7.7	23.1	0.0	5	0(0)	3040(8519)
HT20/LGI		MCS6	9.6	26.8	0.0	5	0(0)	89(849)
HT20/LGI		MCS7	7.3	18.7	0.0	0	0(0)	2(435)
HT20/SGI		MCS0	4.1	60.3	0.0	3	0(0)	713(1776)
HT20/SGI		MCS1	11.5	90.4	100.0	4	0(0)	3108(7805)
HT20/SGI		MCS2	12.6	70.3	100.0	5	0(0)	8030(18854)
HT20/SGI		MCS3	11.9	53.4	0.0	5	0(1)	18236(36896)
HT20/SGI	B	MCS4	21.9	72.9	100.0	5	0(0)	14039(26831)
HT20/SGI	A	MCS5	25.4	71.0	71.4	5	5(7)	2898(6930)
HT20/SGI		MCS6	9.4	24.7	0.0	5	0(0)	122(885)
HT20/SGI		MCS7	10.2	25.0	100.0	5	0(0)	3(444)

Total packet count:: ideal 114909 5930

Average A-MPDU length: 1.0

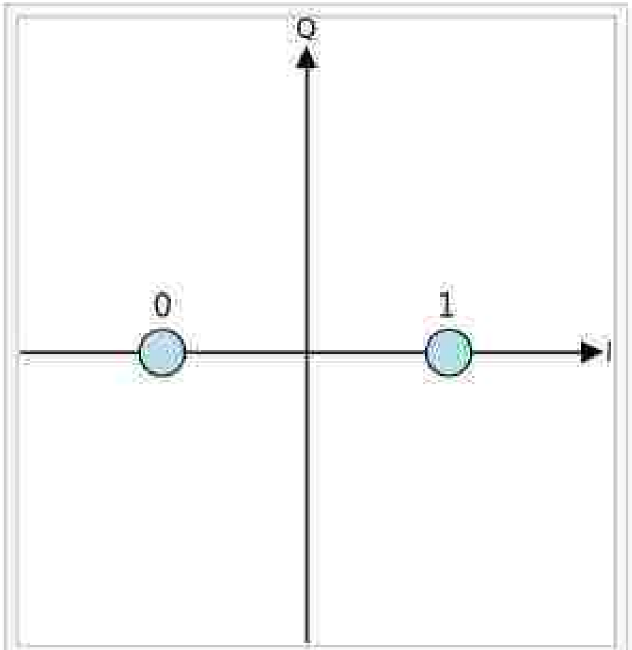
A prototype test showing 25.4 Mbit effective throughput at 57.8 Mbit raw WiFi data rate. (MCS5 SGI = Short guard interval, 71.0% successful packet delivery rate)

Data rates IEEE 802.11n single stream

MCS index	Spatial streams	Modulation type	Coding rate	Data rate (Mbit/s)			
				20 MHz channel		40 MHz channel	
				800 ns GI	400 ns GI	800 ns GI	400 ns GI
0	1	BPSK	1/2	6.5	7.2	13.5	15
1	1	QPSK	1/2	13	14.4	27	30
2	1	QPSK	3/4	19.5	21.7	40.5	45
3	1	16-QAM	1/2	26	28.9	54	60
4	1	16-QAM	3/4	39	43.3	81	90
5	1	64-QAM	2/3	52	57.8	108	120
6	1	64-QAM	3/4	58.5	65	121.5	135
7	1	64-QAM	5/6	65	72.2	135	150

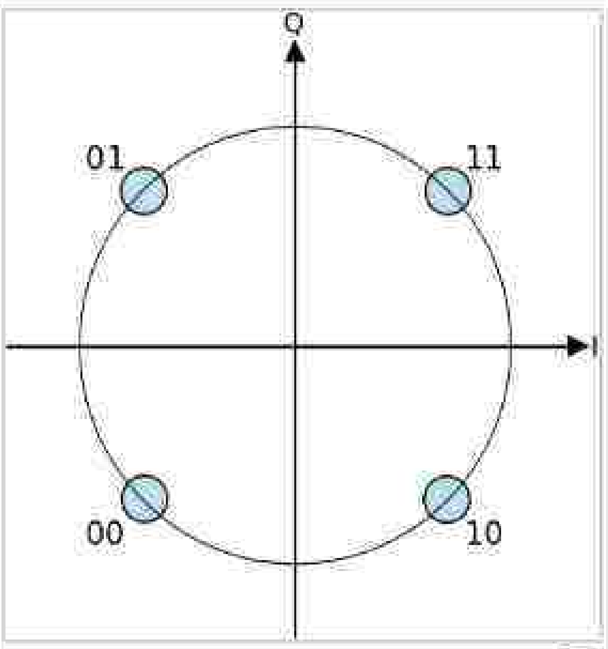
Modulation types and bitrates. More details in the next slides.

Binary Phase Shift Keying BPSK



Constellation diagram example for BPSK.

Quadrature Phase Shift Keying QPSK



Constellation diagram for QPSK with Gray coding. Each adjacent symbol only differs by one bit.

In BPSK, data is modulated by switching the phase of the signal by 180 degrees – hence binary (0 or 1). 1 bit per symbol. Very robust modulation, but slow data rate.

In QPSK, data is modulated by phase shifting the amplitude from an In-Phase-Signal (I) by 4 x 90 degrees (Q = Quadrature), representing 4 different states. 2 bits per symbol.

16-Quadrature Amplitude Modulation (16-QAM)

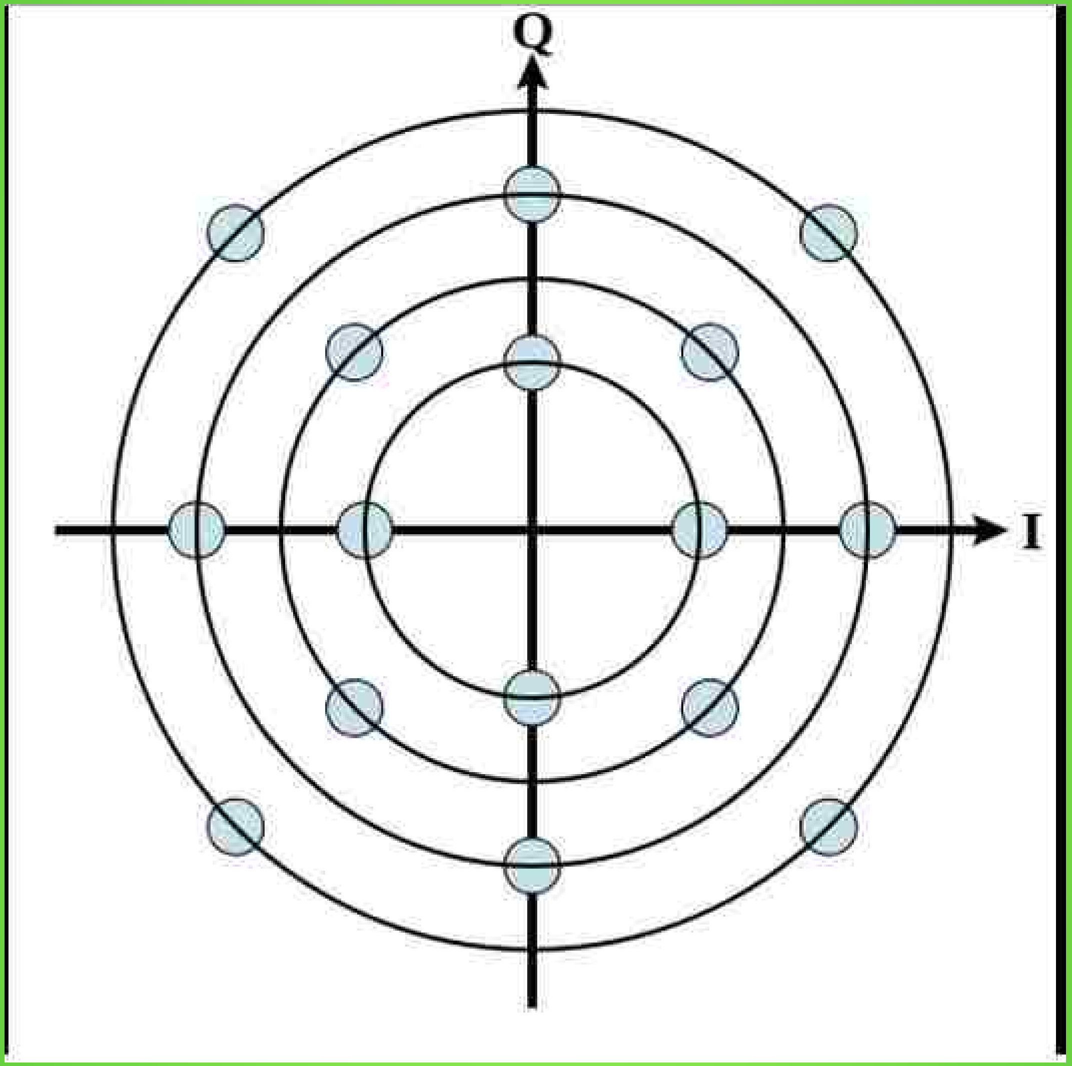


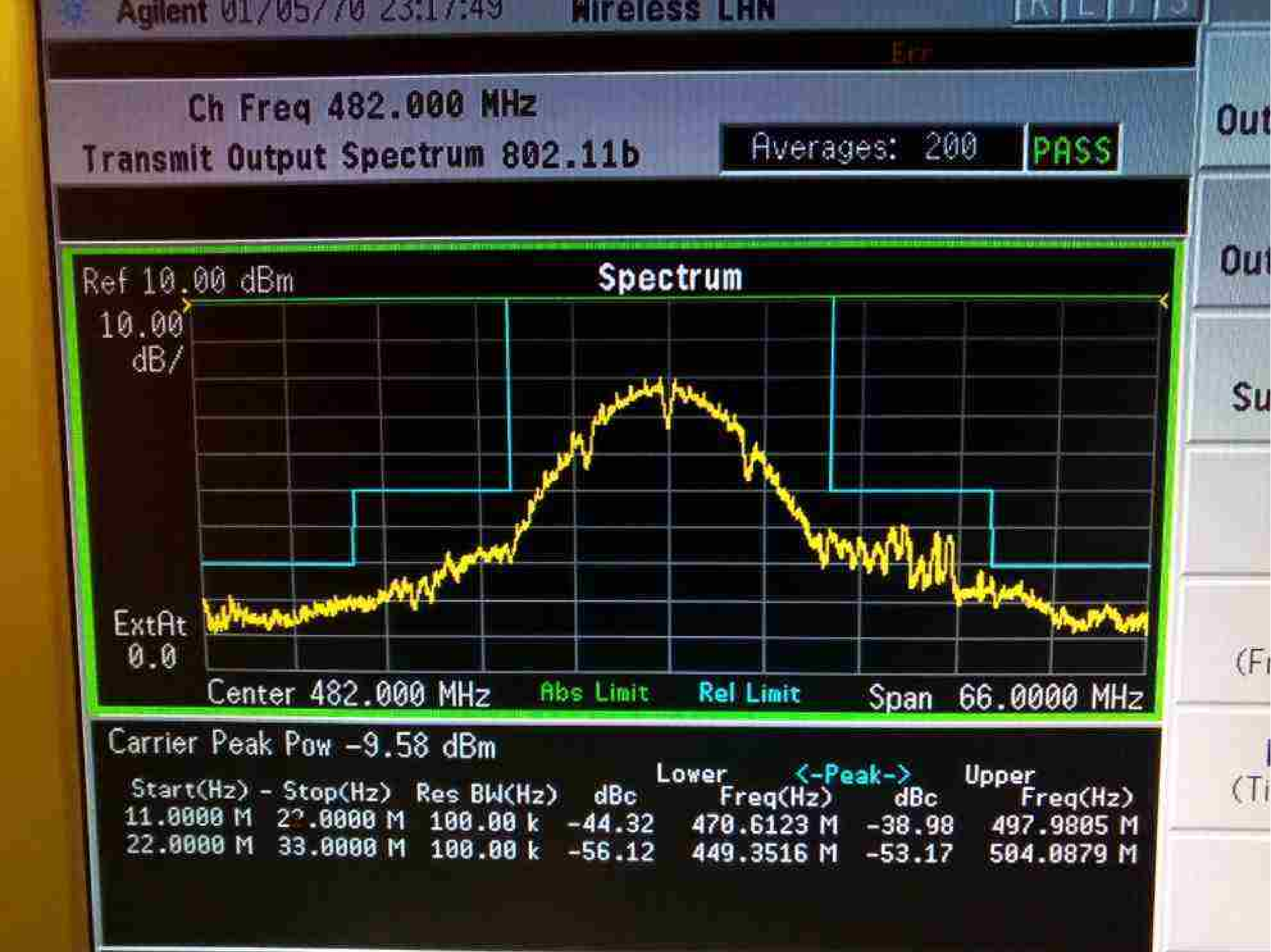
Image by Life of Riley, Public Domain

16-QAM combines amplitude modulation with phase shift modulation. With each symbol 16-QAM communicates 4 bits. The illustration shows circular 16-QAM.

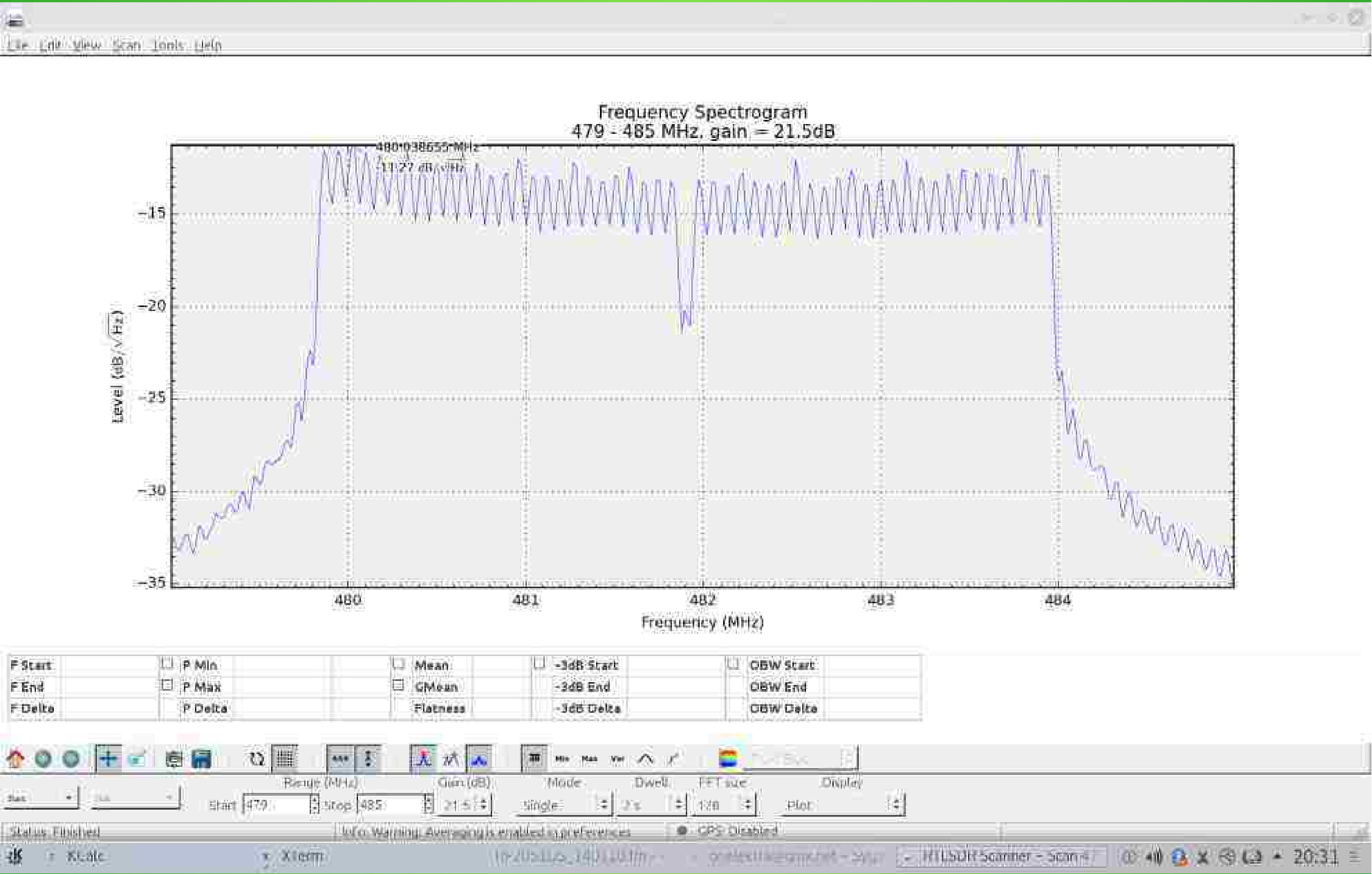
64-QAM carries 6 bits of information in each symbol. As the signal to noise ratio decreases, the areas of the dots become diffuse overlapping clouds, and thus are impossible to decode without error.

Captain Obvious notes:

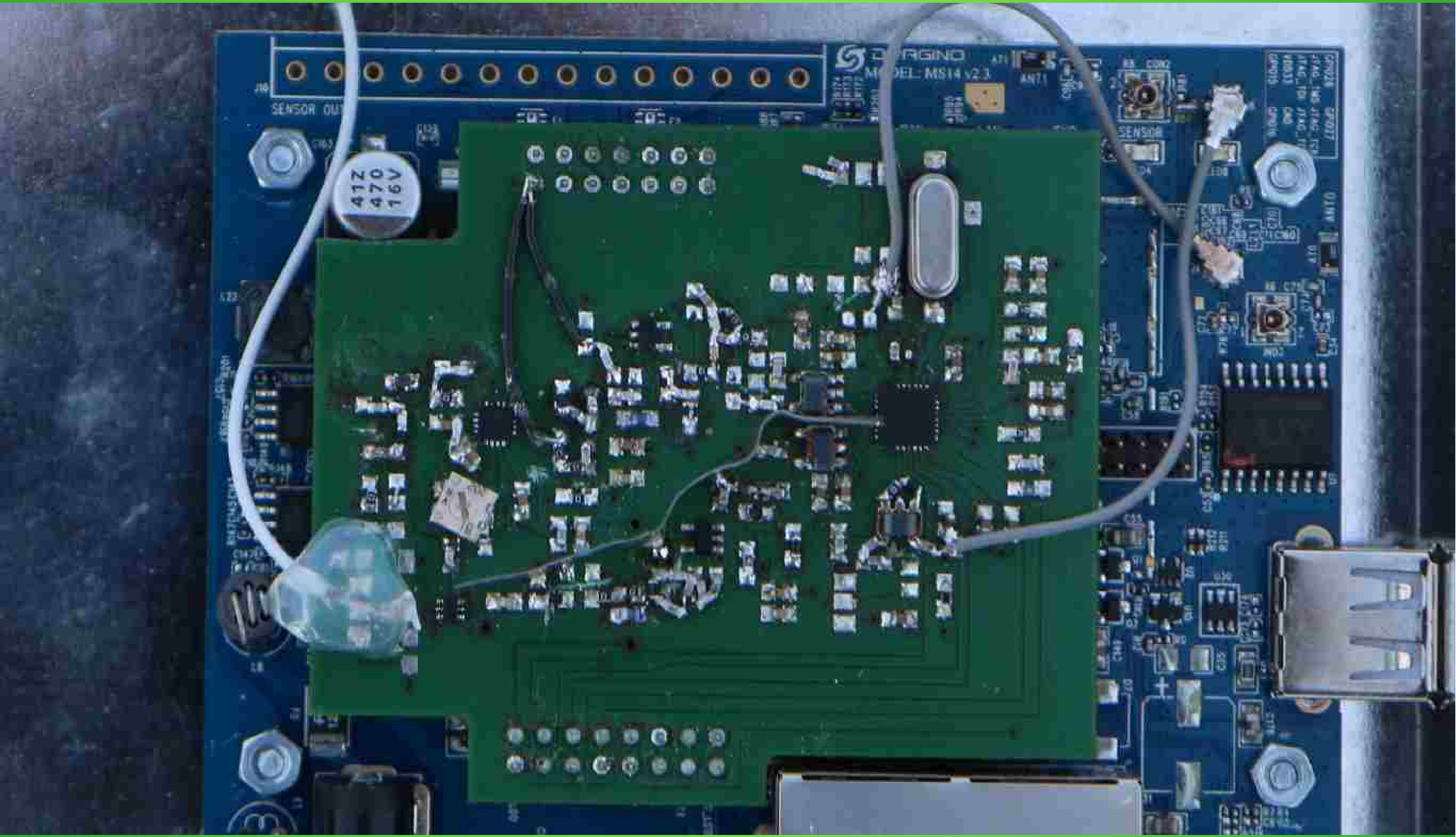
As modulation schemes get more and more complex, i.e. carry more bits per symbol, robustness decreases and the requirement for signal to noise ratio gets more and more demanding.


Agilent 01/05/70 23:17:49
Wireless LAN
Ch Freq 482.000 MHz
Transmit Output Spectrum 802.11b
Averages: 200
PASS
Ref 10.00 dBm
Spectrum
10.00
dB/
ExtAt
0.0
Center 482.000 MHz
Abs Limit
Rel Limit
Span 66.0000 MHz
Carrier Peak Pow -9.58 dBm
Lower
<-Peak->
Upper
Start(Hz) - Stop(Hz) Res BW(Hz) dBc Freq(Hz) dBc Freq(Hz)
11.0000 M 22.0000 M 100.00 k -44.32 470.6123 M -38.98 497.9805 M
22.0000 M 33.0000 M 100.00 k -56.12 449.3516 M -53.17 504.0879 M

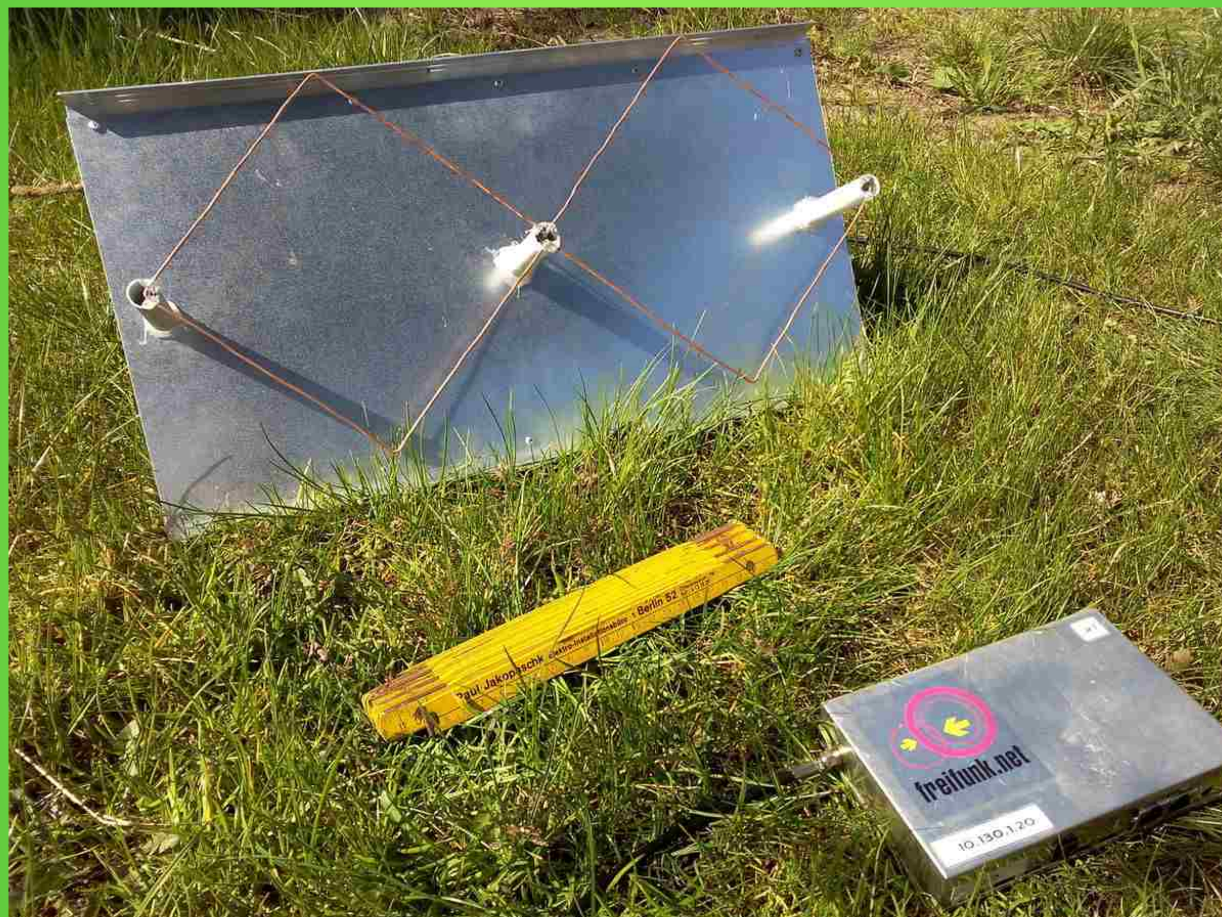
Spectrum pics



Actual implementation


MODEL: MS14 v2.3
SENSOR OUT
SENSOR
41Z
470
16V

Bi-Quad Antenna for 62cm (~9.5dBi gain)



The bi-quad seen from the back-side mounted at the Zwingli-Kirche

Lots of objects (trees, bushes) in our Fresnel-Zone... but the link works!

Summary of our TV-Whitespace experiences:

- We have working prototypes that perform reasonably well. The cost is reasonably low, so price vs performance is OK. The solution is flexible, so can be adopted to other – unused – bands.
- Converting signals up and down adds some friction – i.e. additional noise from the mixer. So a generic WiFi chip designed for the UHF-band would have advantages in price, effort, power consumption and performance. This doesn't come as a surprise. Still, the transverter is an alternative to existing solutions with a software defined radio with regards to cost and power consumption. At a fraction of the cost, actually.
- We can use the IEEE802.11b,g,n MAC protocol in the band at 5 MHz, 10 MHz, 20 Mhz and 40 MHz bandwidth. Implementing a different MAC protocol would be more difficult. Other bandwidths like 3 MHz or 8 MHz are theoretically possible. Ubiquiti has them with the same WiFi chipsets, but they will surely not share their driver modification secrets with us.
- The opportunity to use additional frequency bands as an addition to the overcrowded spectrum is great and should be communicated also politically. This is getting more important, as LTE-U is going compete in an unfair way with WiFi in the 5 GHz band. We have to act politically against the unfriendly takeover of 5 GHz, but this is a different subject.
- Not surprisingly, we have less attenuation through bushes and trees. So we don't suffer from objects in the Fresnel-Zone quite as much as 2.4 GHz or 5 GHz. Hence, we can cover a larger, broader area on the ground.
- The diameter of the Fresnel-Zone is also larger, as it is increases with the wave length. This comes as a trade off. Not so good for high bandwidth point to point links, if we plan for an unobstructed Fresnel-Zone.
- Since objects in the Fresnel-Zone are less likely to break the wave front at UHF compared to 2.4 GHz, wave front polarisation doesn't change (rotate) quite as much. Hence, we can seperate wave fronts from other systems on the same channel by up to 20dB, if the polarisation is different i.e. horizontal vs vertical linear polarisation.
- High gain directional antennae are considerably larger. Also no surprise.

More Info:

http://wiki.freifunk.net/MABB:TVWS

With thanks to the Medienanstalt Berlin-Brandenburg http://mabb.de

Thanks!